



Creep Relaxation around Surface Flaws in Internally Pressurised Tubes

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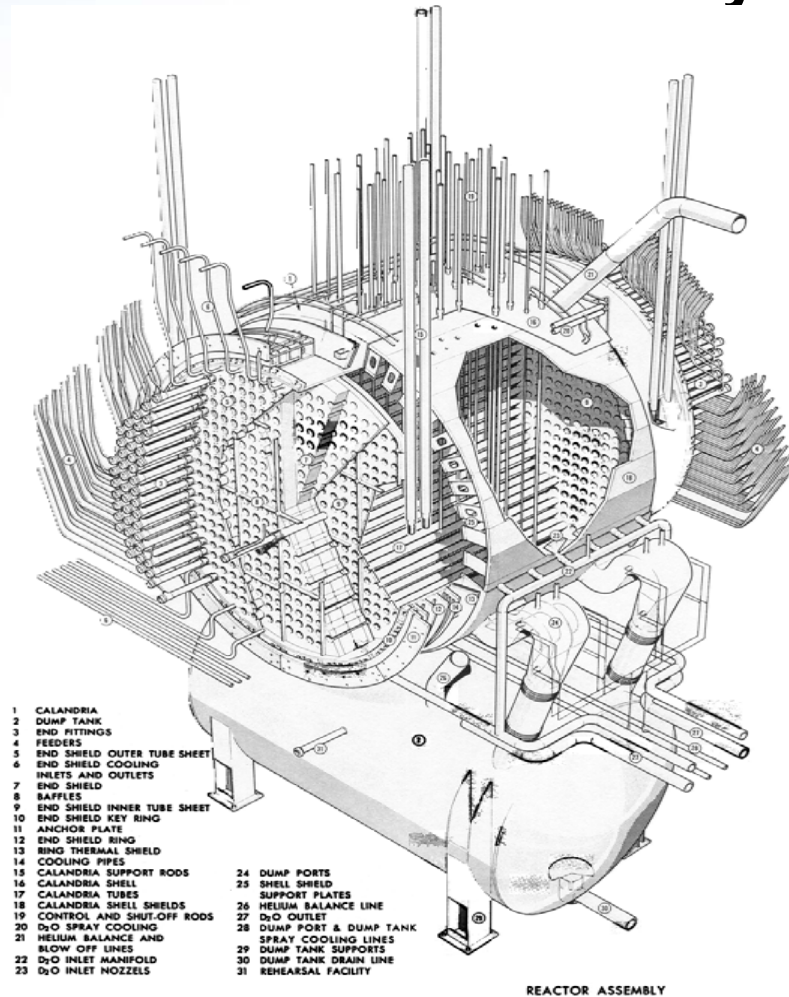


OUTLINE

- **Background**
- **Neutron Diffraction Set-up and Results**
- **Modeling**
- **Comparison of Neutron Diffraction and Numerical Results**
- **Summary**



Candu Power Generation System



Fuel Channel

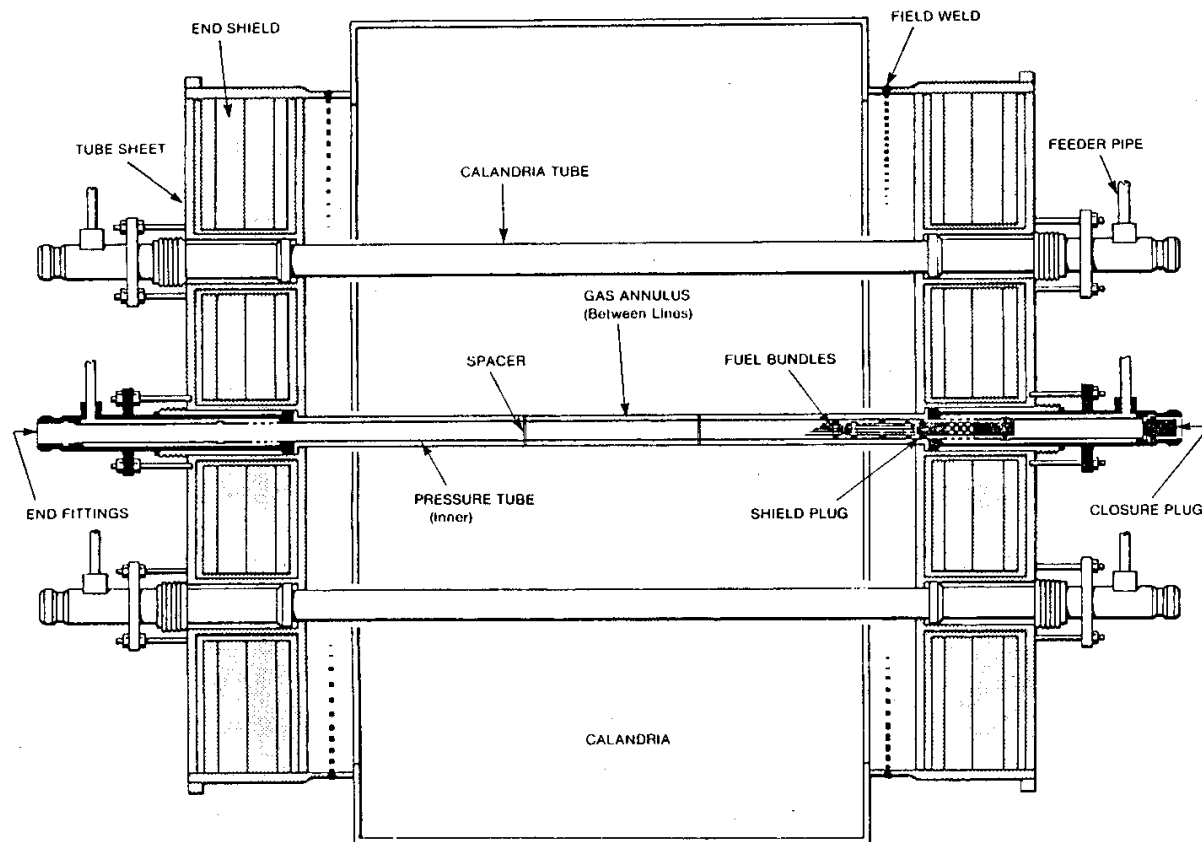
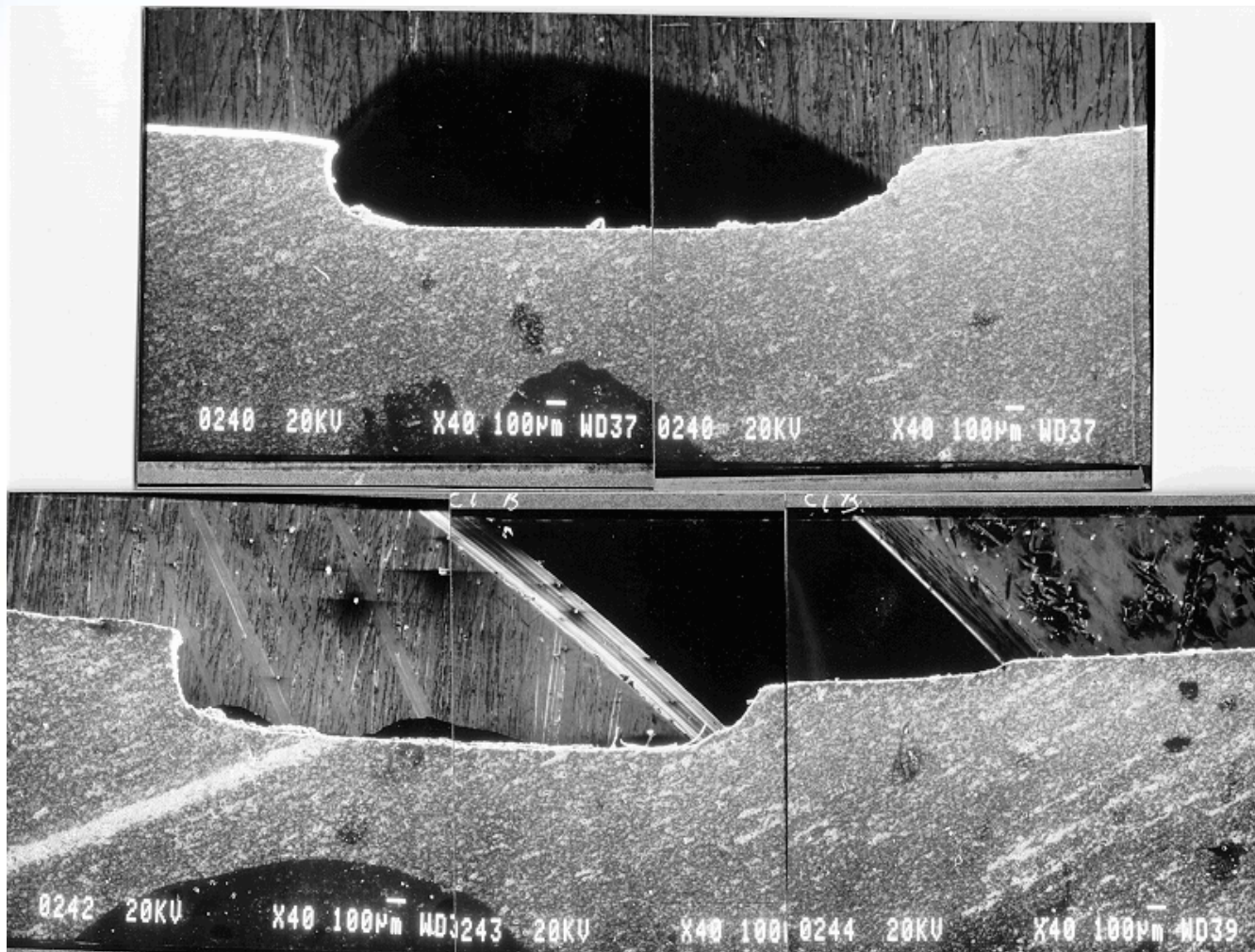


FIGURE 2.2.3 REACTOR CORE SCHEMATIC

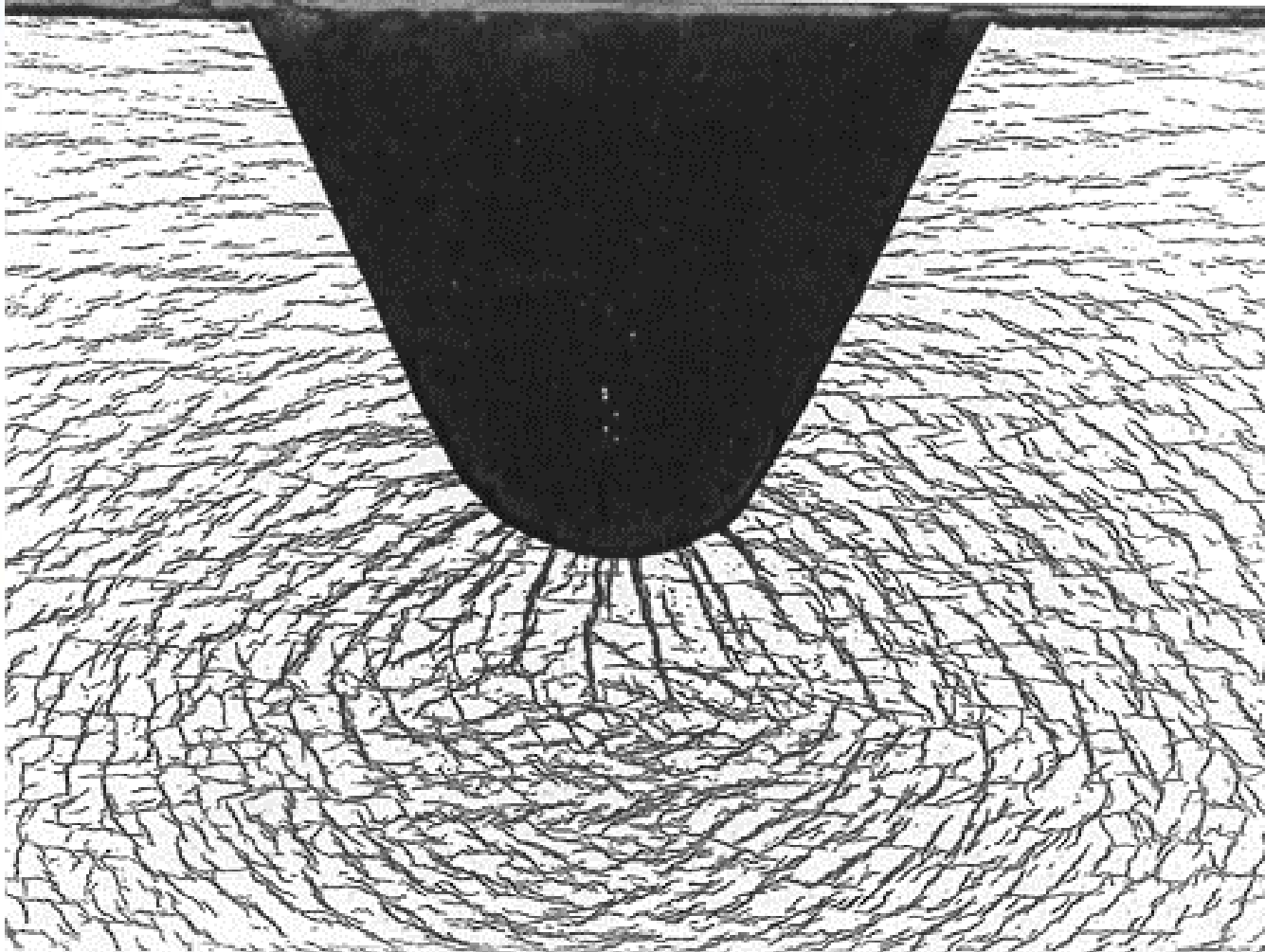


Fretting/Debris Flaws



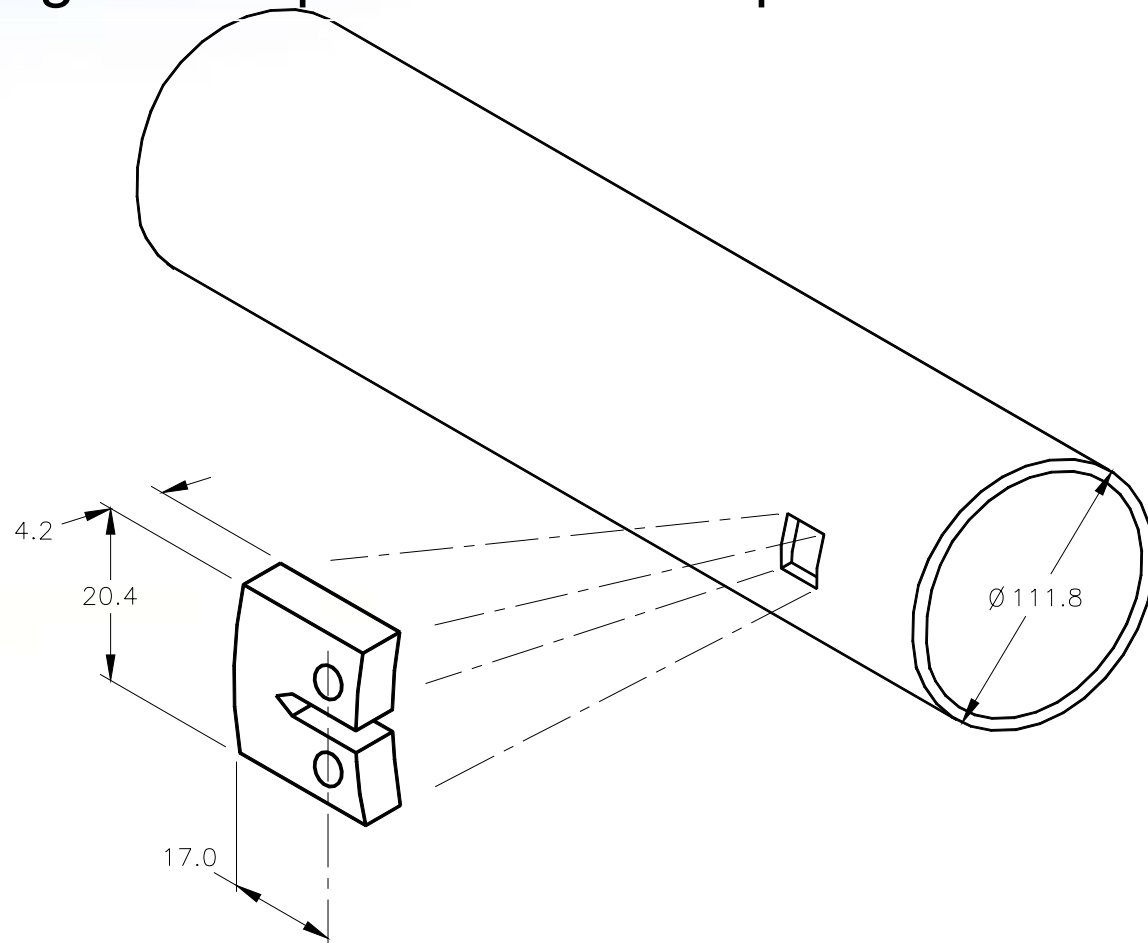


Zirconium Hydride Precipitation



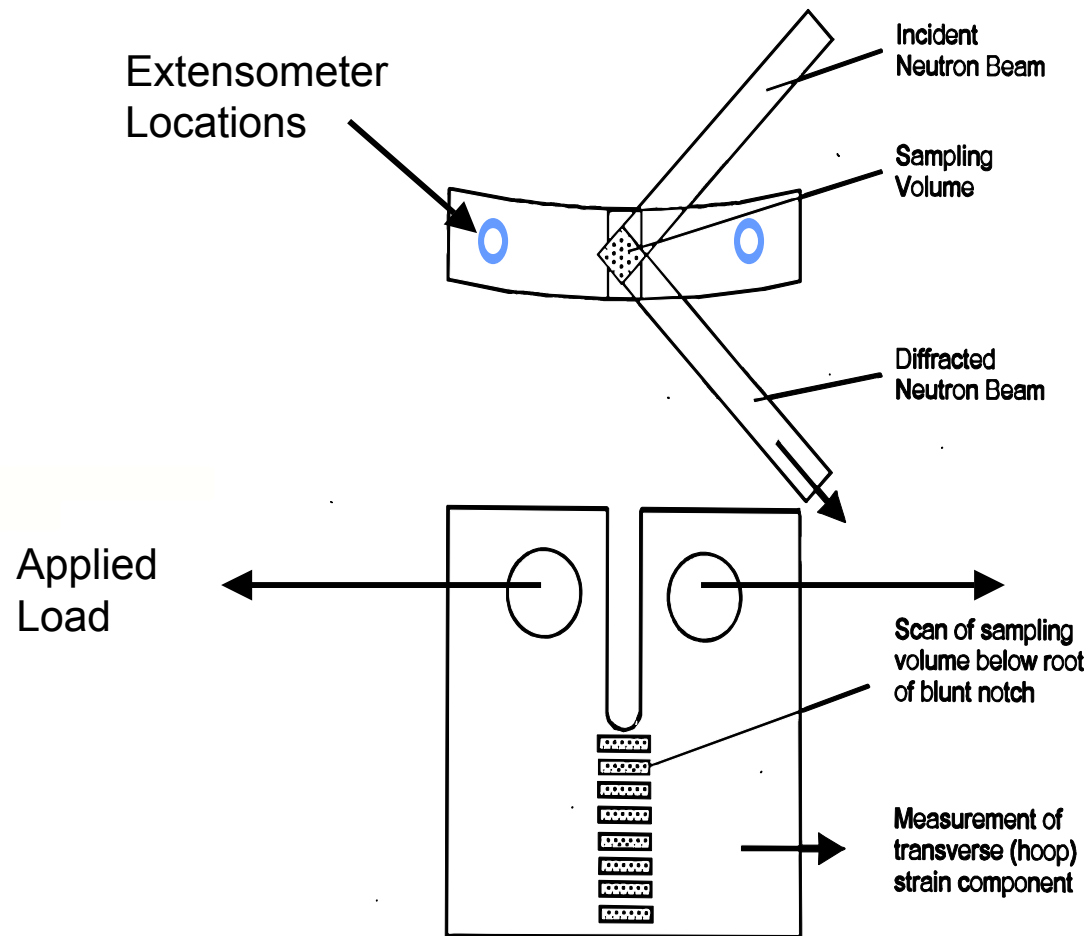


“Cookie-cutter” method of creating a compact toughness specimen from a pressure tube.





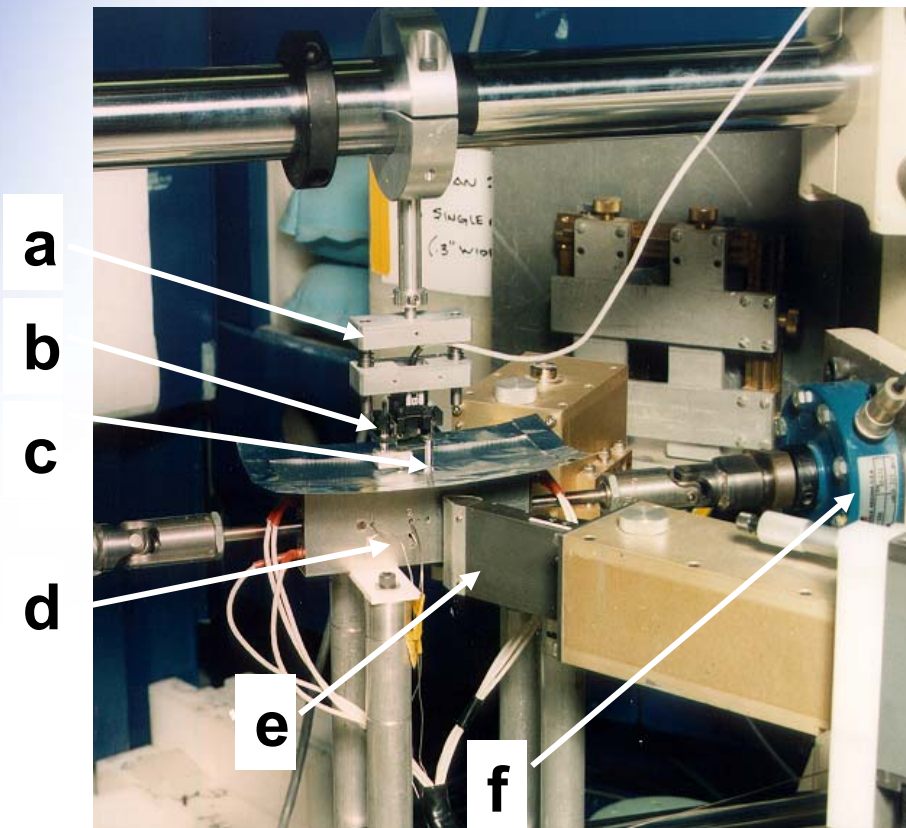
Neutron Scanning Path





Neutron Scattering Apparatus for Constant Strain CTS

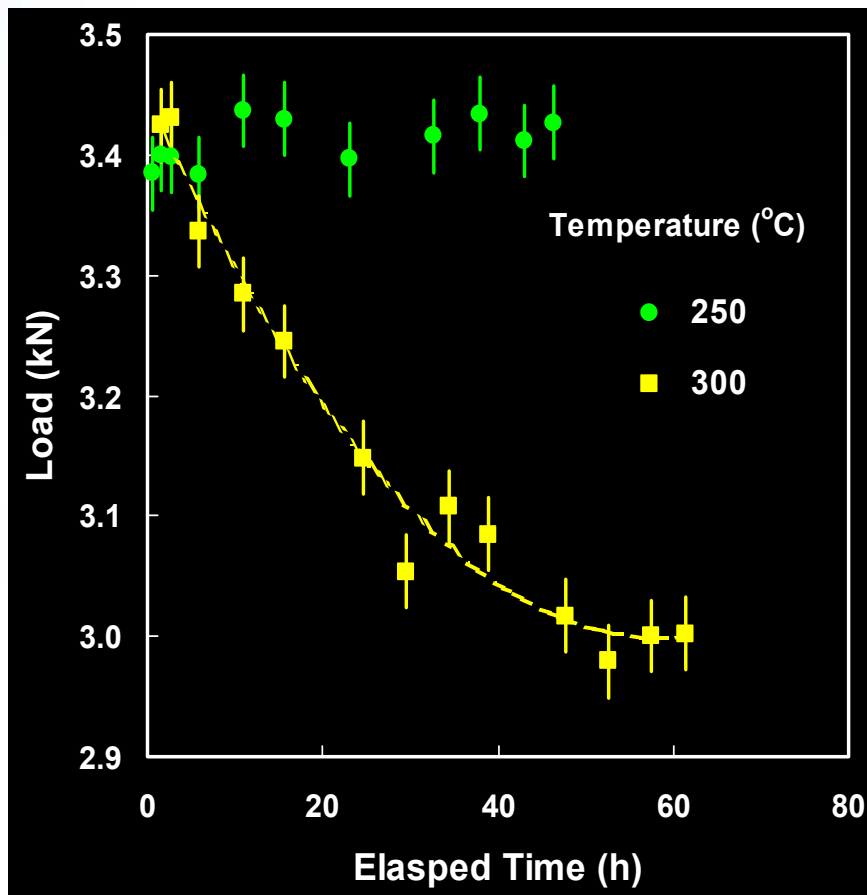
$T = 250^{\circ}\text{C}, 300^{\circ}\text{C}$



- a) spring-loaded mount
- b) extensometer
- c) glass-rod extension
- d) thermocouples
- e) neutron beam-defining slit (0.5 mm x 2 mm)
- f) load cell



Macroscopic Stress Relaxation Zr-2.5Nb CT Specimen

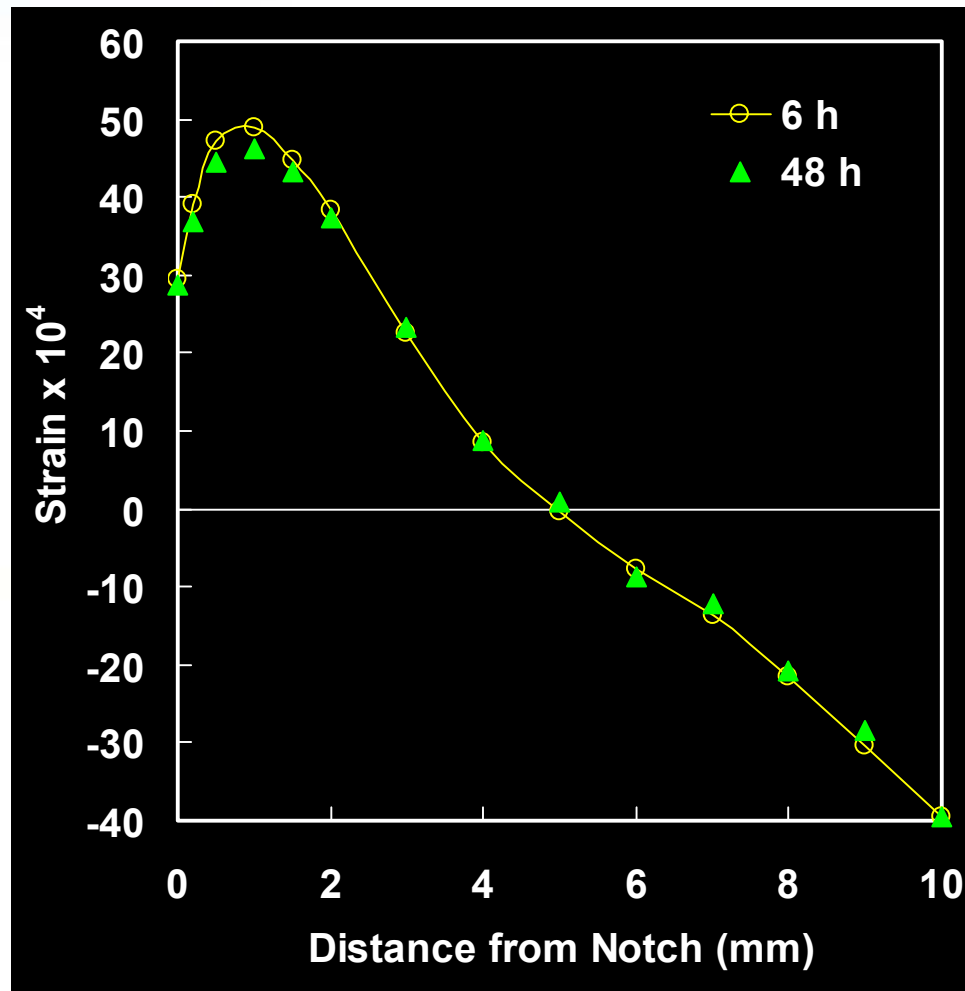


Average readout of
load cell over each
scan of positions.

Temperature stability
on specimen $\pm 2^{\circ}\text{C}$.



Distribution of Strain on the CTS Notch Plane $T=300^{\circ}\text{C}$





Material Constitutive Law

The highly anisotropic plastic and creep properties of the Zr-2.5Nb HCP material are simulated using a non-linear self-consistent polycrystalline code, SELFPOLY.

$$\dot{\underline{\underline{\varepsilon}}} = f(\varepsilon_c^{ef}, T, \sigma^{ef}) \dot{\underline{\underline{\varepsilon}}}^{IT}(\underline{\underline{\sigma}})$$

$\dot{\underline{\underline{\varepsilon}}}$ is the strain rate tensor,

$f(\varepsilon_c^{ef}, T, \sigma^{ef})$ is a scalar function that accounts for work hardening and temperature changes

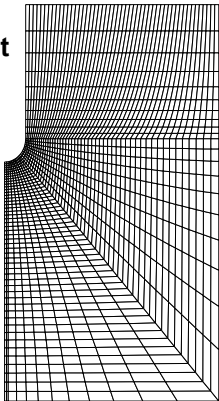
$\dot{\underline{\underline{\varepsilon}}}^{IT}(\underline{\underline{\sigma}})$ is the tensor from the interpolation table that gives the anisotropy of the material at a stress tensor $\underline{\underline{\sigma}}$.

The interpolation table is determined using SELFPOLY, which represents the weighted average of the creep response exhibited by individual crystal grains. This has been incorporated as a material subroutine into the finite element code, H3DMAP

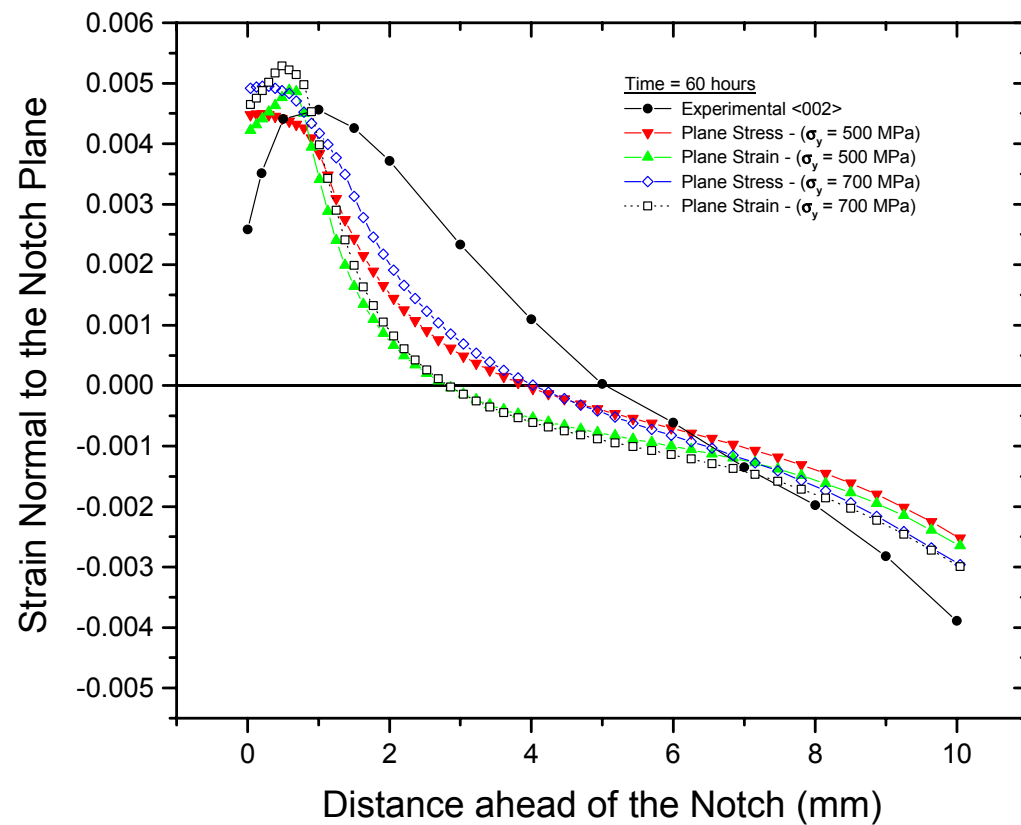
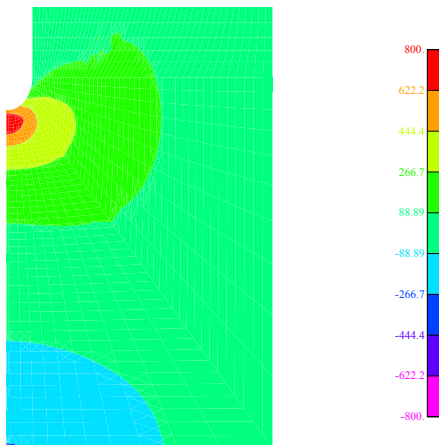


Analytical(2-D) / Experimental Comparison of the Elastic Strain Normal to the Notch Plane

2-D Finite Element Mesh

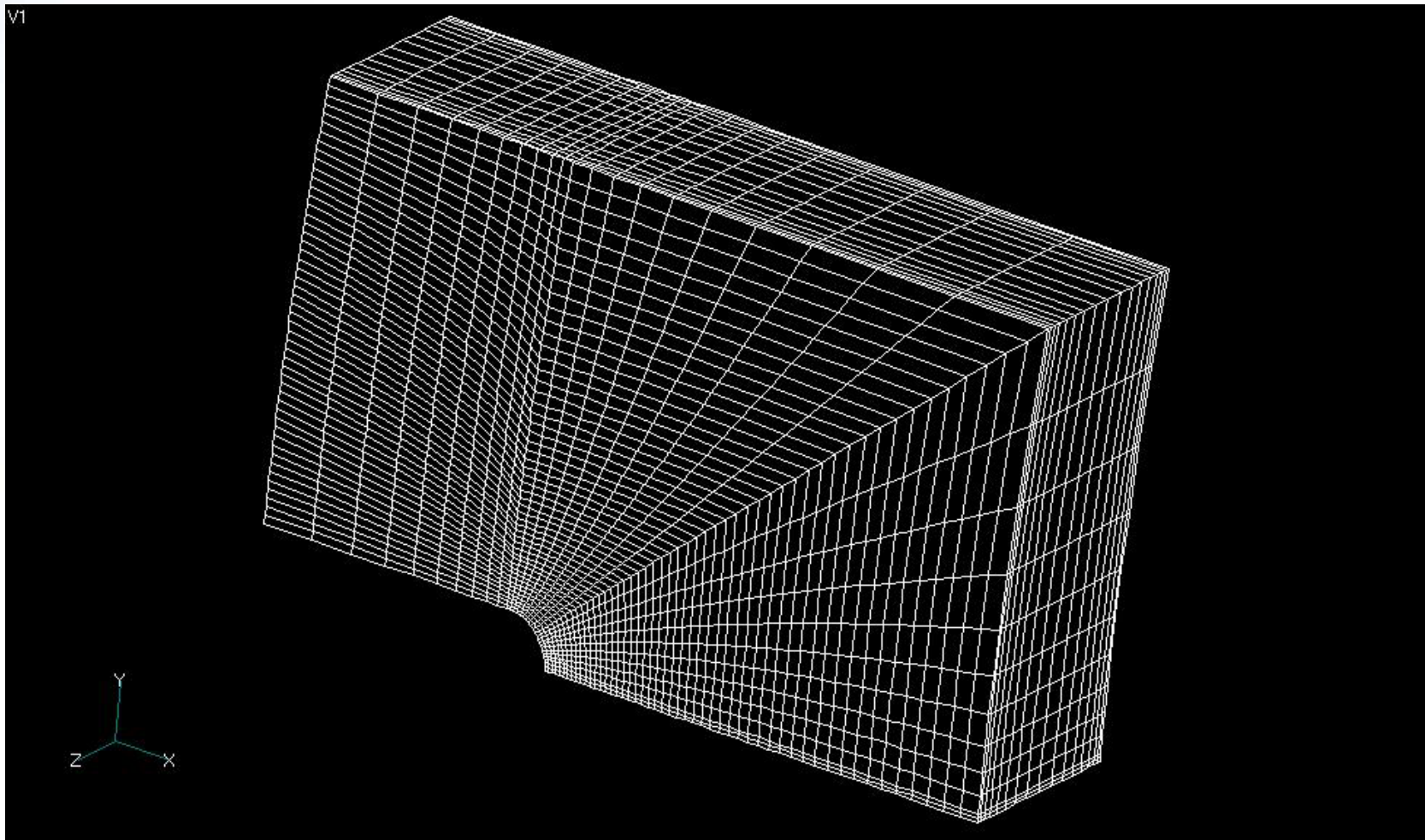


Stress Contours Normal to the Notch Plane at 0.0h



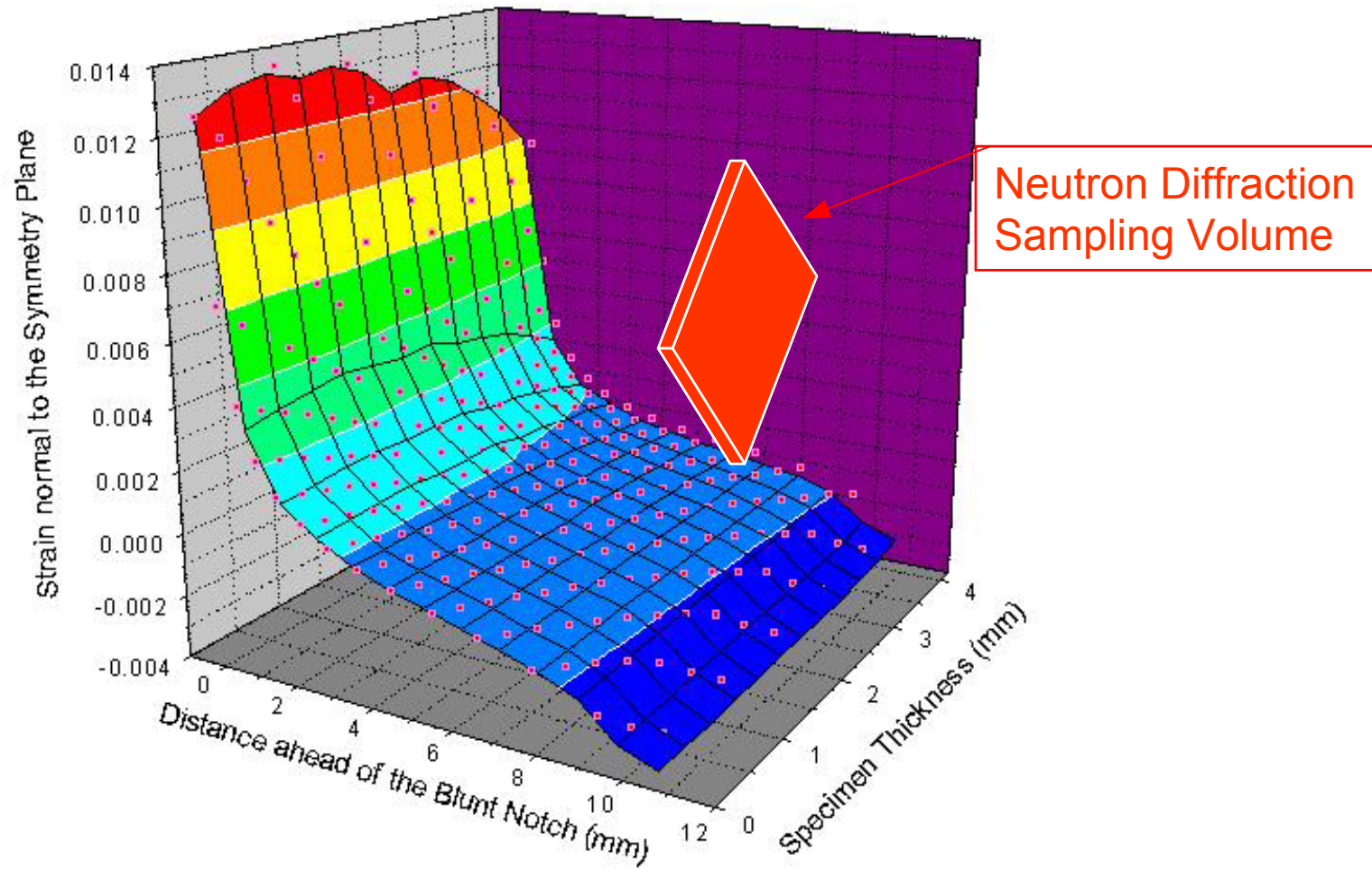


3-D Curved CTS Model



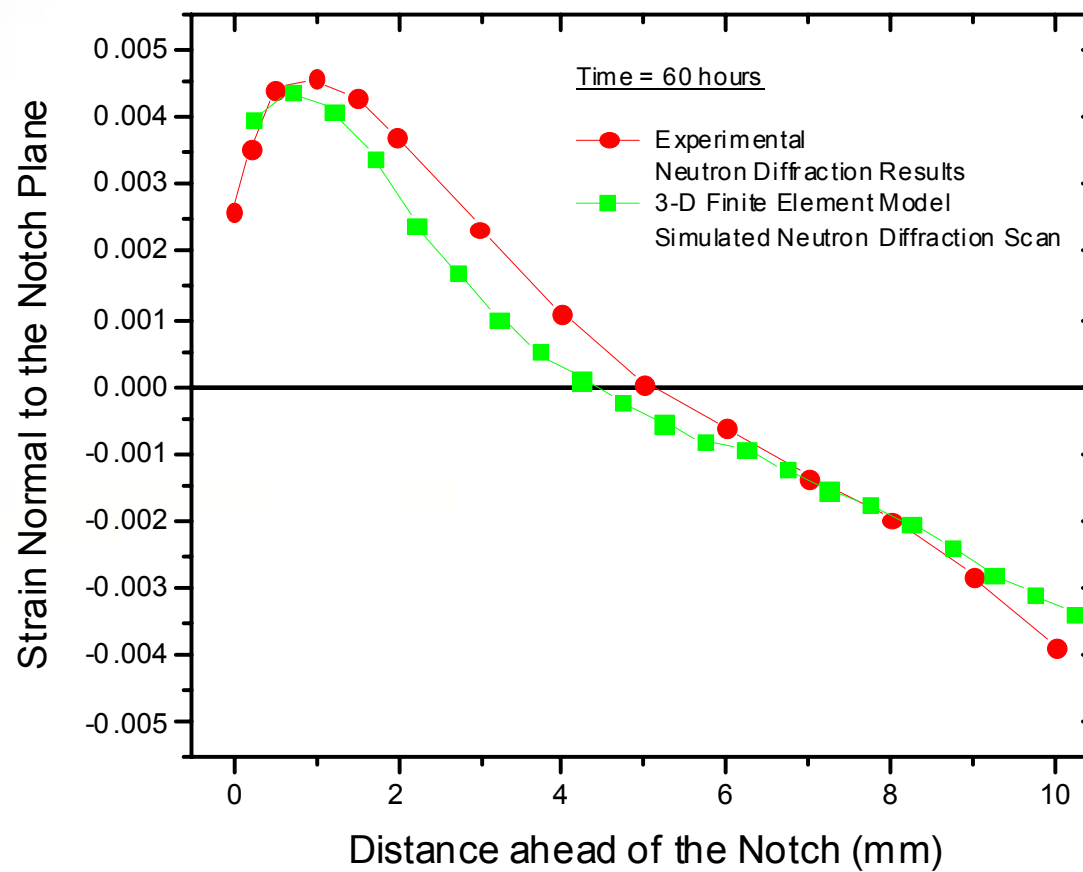


3-D Strain Variation on the Notch Plane Neutron Sample Volume





3-D Analytical / Neutron Diffraction Notch Plane Results





Summary

- Both the analytical and experiment techniques have shown that the stress relaxation that occurs ahead of the notch is primarily due to thermal creep
- A good agreement is found when the 3-D analytical results are determined within the volume of the neutron diffraction scanning technique.
- Constant load tests are currently being evaluated
- Neutron scanning rate is not fast enough